Tire Induced Surface Cracking

due to Extreme Wheel Loads

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Background

Surface Distresses at Amsterdam Airport Schiphol

Amsterdam Airport Schiphol (AMS)

- 52 MAP in 2013
- 450,000 annual aircraft movements
- Large share of intercontinental flights with wide-bodies

Taxiway Pavement

- 200 mm polymer modified asphalt
- PG 76-22 SBS-modified binder
- 700 mm cement treated base
- Subgrade CBR 1-2

Recurring Surface Distresses

- Entry TWY A8 towards RWY 24
- Circulation TWY A at wide-body F-pier
- Both locations subject to high shear
- Multiple resurfacings executed

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Typical Examples

Approach

1. Literature Review

2. Numerical calculation of stresses at pavement surface

3. Check stresses against Mohr-Coulomb

4. Compare numerical results with analytical model

5. Identify critical failure parameters

6. Collect field data on asphalt performance characteristics

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Conclusions

1. Extreme but realistic combinations of tire pressure and shear can cause surface cracking

2. Surface cracking is a strength issue and not a stiffness issue

3. Horizontal tensile stress at wheel edge is critical

4. Mixture cohesion is crucial to resist surface cracking

5. Cohesion drops with increasing temperature; hence risk of surface cracking is highest at elevated temperatures

6. ITS-test is simple test to determine cohesion

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Recommendations

1. Analytical model gives insight into sensitive parameters but requires further validation due to rapid change of tensile stress at wheel edge

2. Effect of non-uniform stress distribution is likely to increase edge stresses, but has not been studied

3. Failure is defined by single loading event. Fatigue may have to be considered

4. Interface condition between asphalt layers is a known cause of surface cracking but has not been studied

5. Impact of non-circular contact area needs further study

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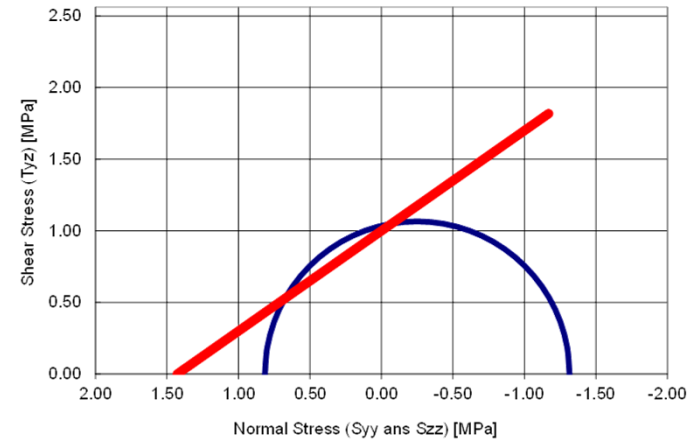
Failure as per Mohr-Coulomb

Factor of Structural Robustness F_{SR}

$$F_{SR} = c \times \cos(\phi) \times \left(\sqrt{\left(\tfrac{1}{2}S_{zz} - \tfrac{1}{2}S_{yy}\right)^2 + T_{yz}^2} + \tfrac{1}{2}\left(S_{zz} + S_{yy}\right)\sin(\phi) \right)^{-1}$$
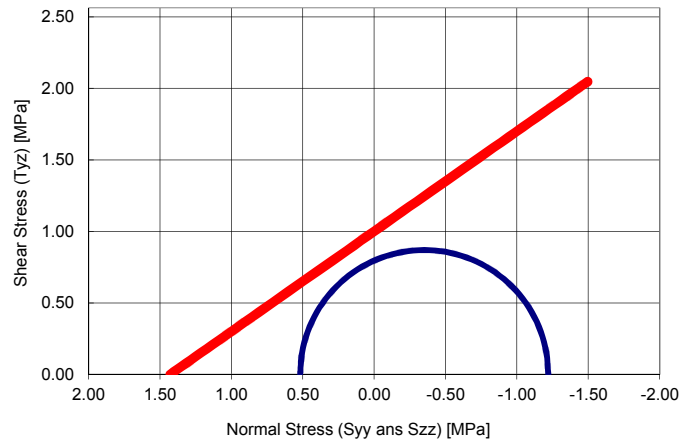
Fsr > 1

No Failure

Fsr < 1

Failure

Numerical Calculations

Pavement Structure

Polymer Modified Asphalt PG76-22 SBS-binder	**200 mm**	elastic / visco-elastic c = 1 MPa, φ = 35°
Cement Treated Base	**700 mm**	**linear elastic E > 5,000 MPa**
Sand Sub-Base	**400 mm**	**linear elastic**
Clayey Subgrade		**Combined E = 40 MPa**

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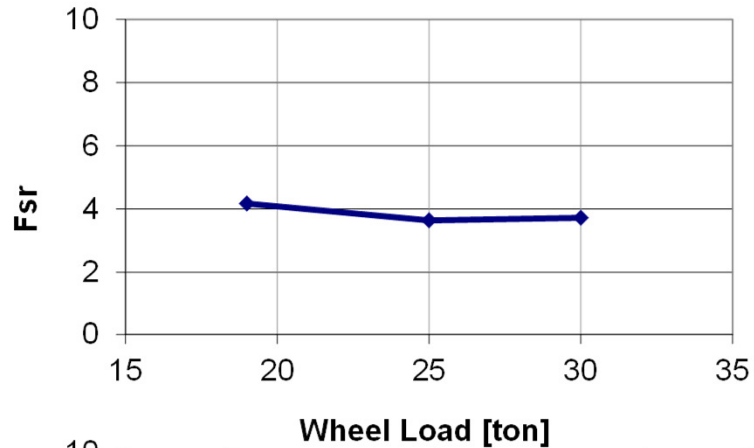# Numerical Calculations

Loads

- Single wheels only. Multiple wheels → no interaction

- Uniform vertical and horizontal stress distribution over circular contact area

- Load characteristics:

Wheel Load	Tire Pressure
19 t	0.86 MPa
19 t	1.45 MPa
25 t	1.54 MPa
30 t	1.75 MPa

Numerical Calculations

Results – Straight Moving Loads
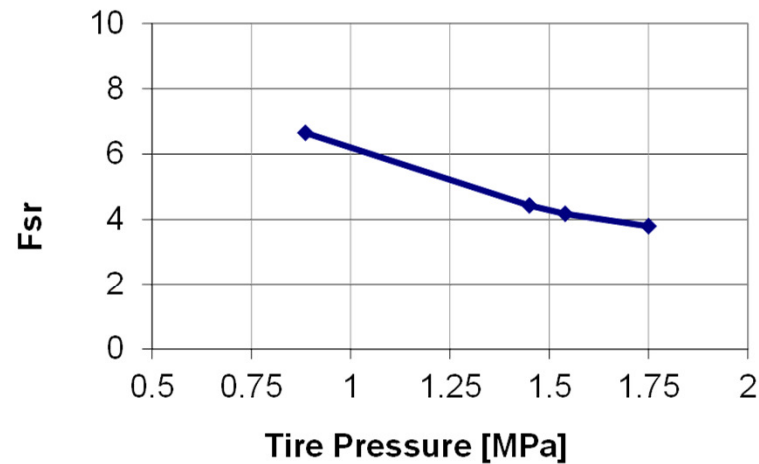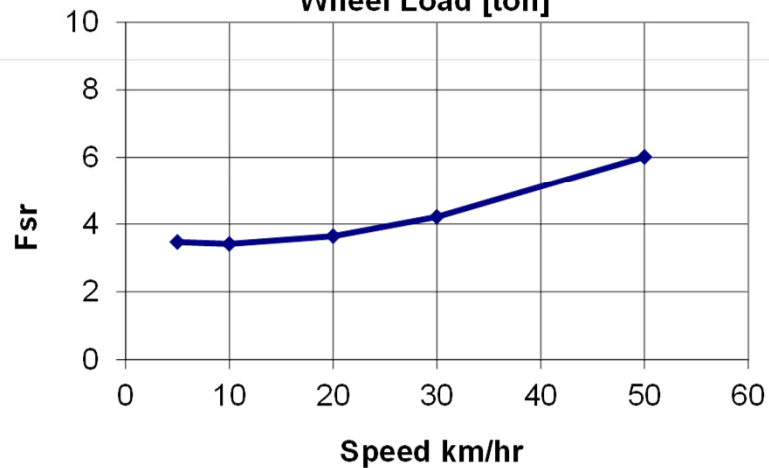
- No risk of failure with straight moving loads, uniform stress and c = 1 MPa

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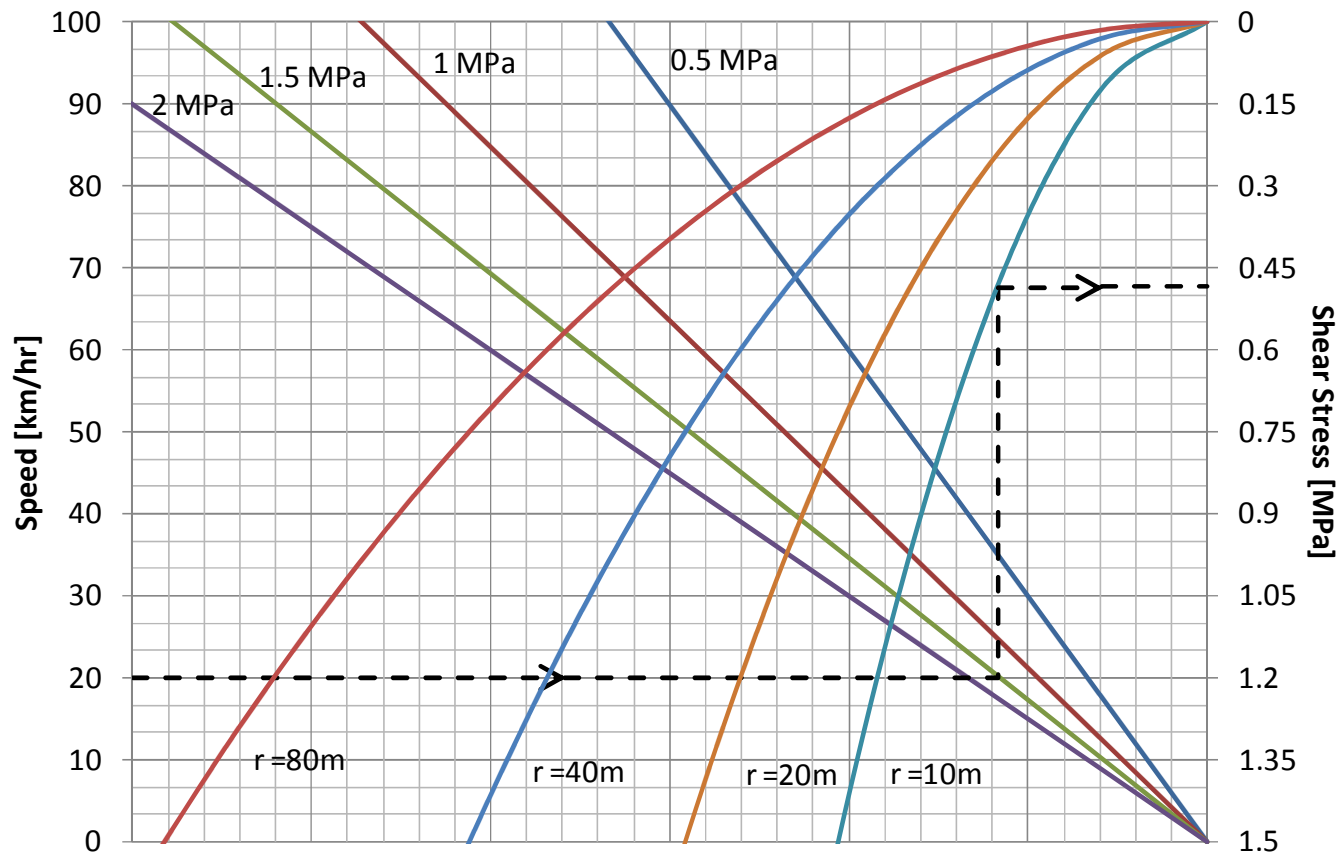# Numerical Calculations

Loads in Curves

- Standard taxiway curve 55 m centreline radius

- Wide-body mean gear (B777) = 35 m, 1.54 MPa tire pressure

- Horizontal shear by:

  - σ = tire pressure [MPa]
  - v = speed [km/hr]
  - R = curve radius [m]
  - τ = shear stress [MPa]

$$\tau = 7.87 \cdot 10^{-3} \times \frac{\sigma (v)^2}{R}$$

Speed	Horizontal shear	G-force
20 km/hr	0.14 MPa	0.09g
30 km/hr	0.31 MPa	0.20g
50 km/hr	0.85 MPa	0.56g

Numerical Calculations

Shear Stress Nomogram

Numerical Calculations

Results – Loots in Curves
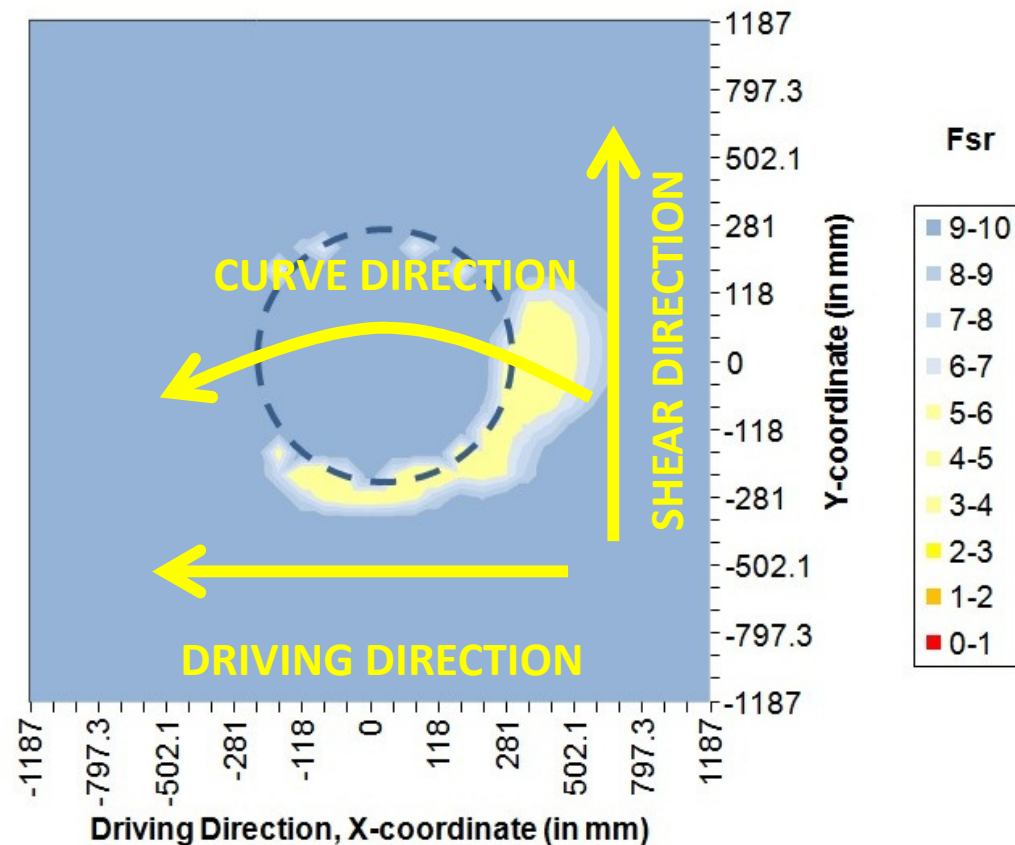
- Tire Pressure = 1.54 MPa

- R = 35 m

- Speed = 20 km/hr
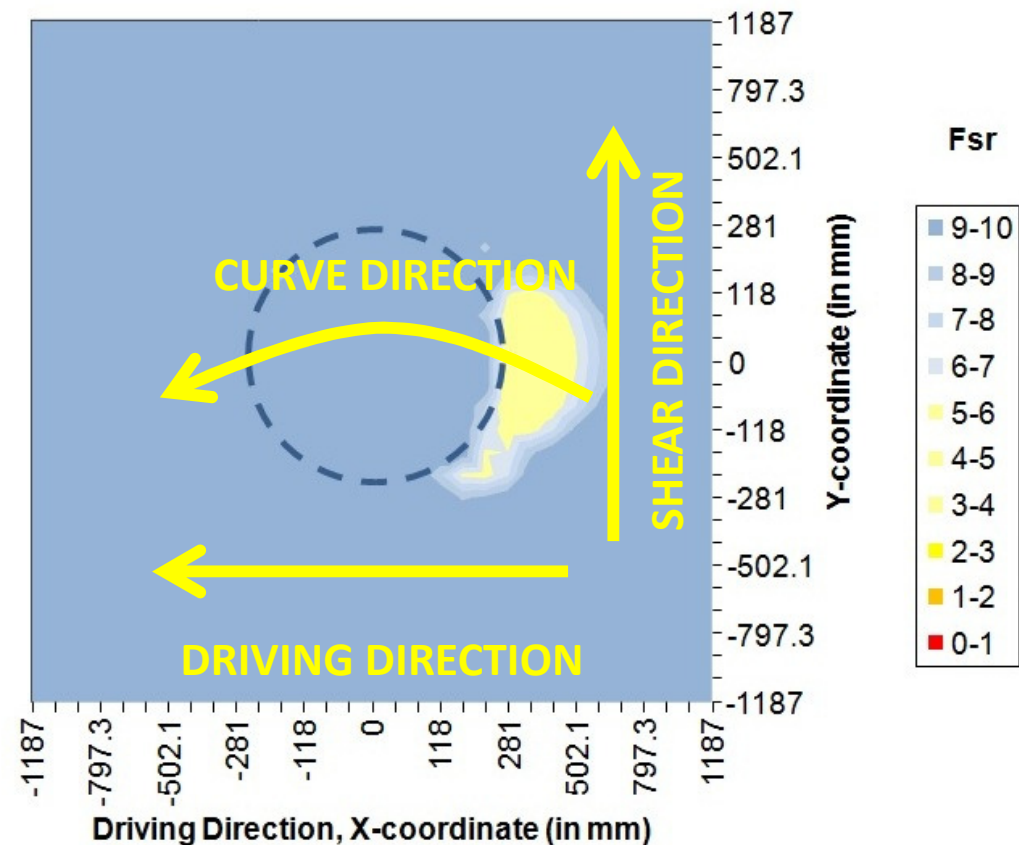
B777 r=35m v=20kmh

Numerical Calculations

Results – Loops in Curves

- Tire Pressure = 1.54 MPa

- R = 35 m

- Speed = 30 km/hr

B777 r=35m v=30kmh

Numerical Calculations

Results – Loads in Curves

- Tire Pressure = 1.54 MPa

- R = 35 m

- Speed = 34 km/hr
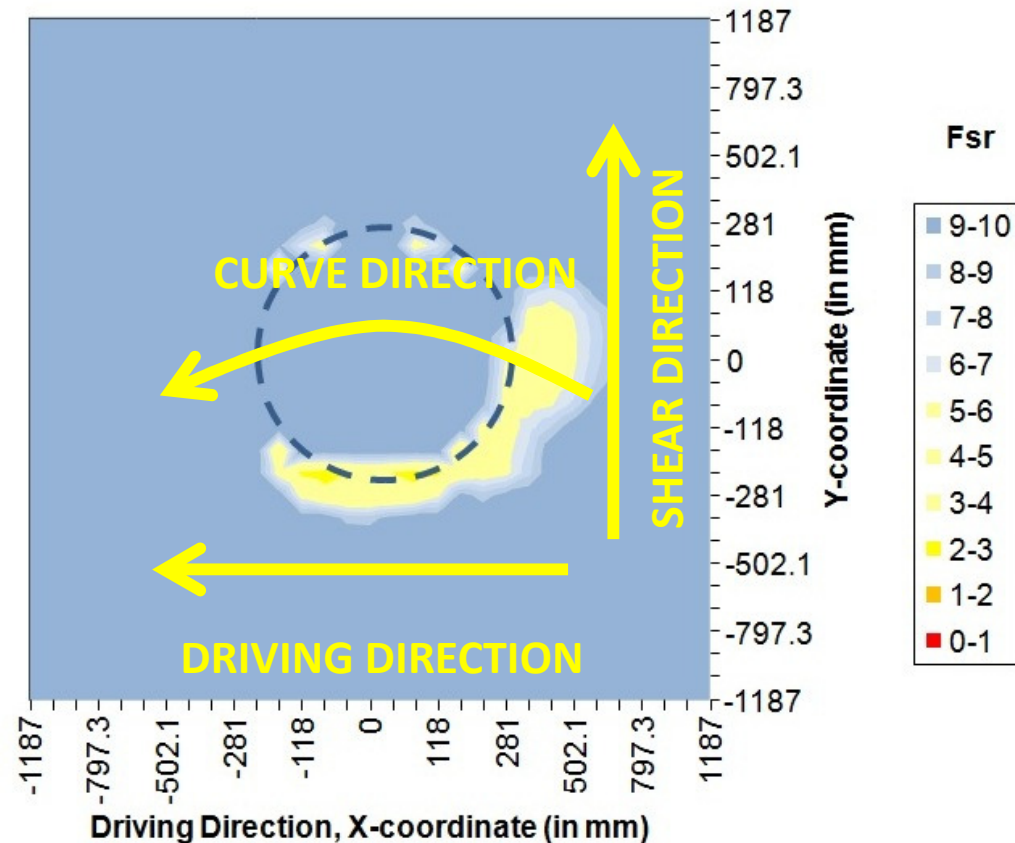
B777 r=35m v=34kmh
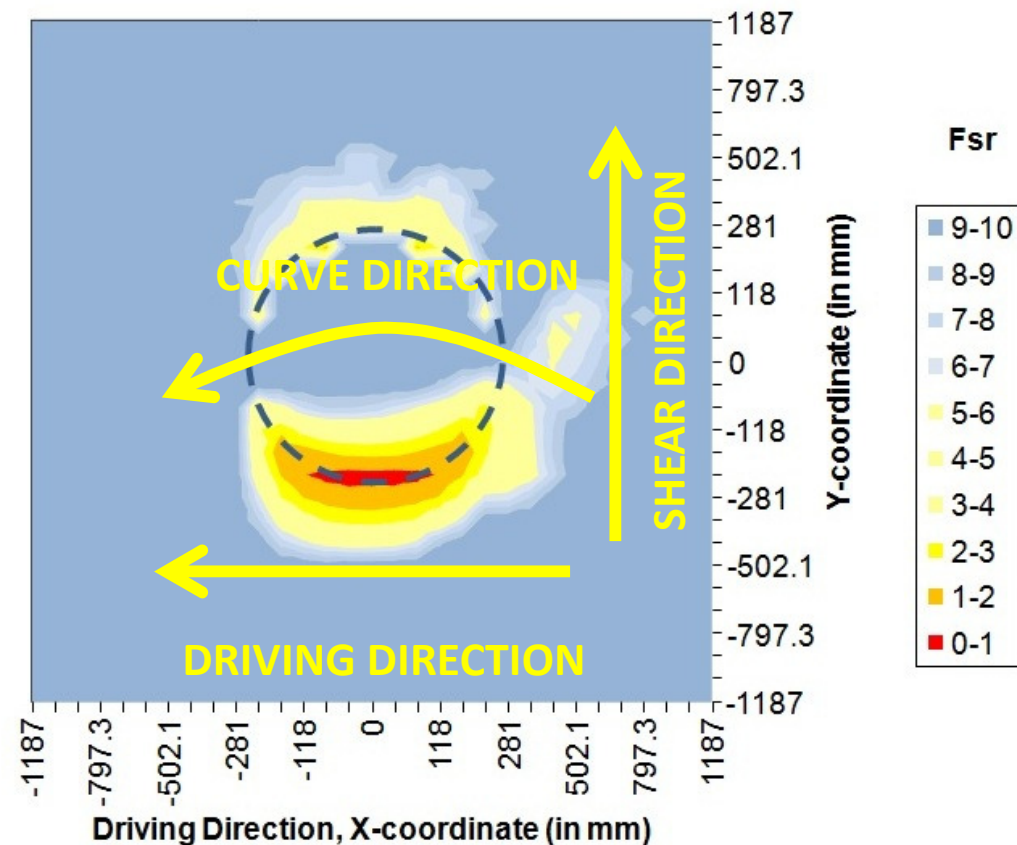
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Numerical Calculations

Results – Loses in Curves

■ Tire Pressure = 1.54 MPa

■ R = 35 m

■ Speed = 50 km/hr

B777 r=35m v=50kmh

Numerical Calculations

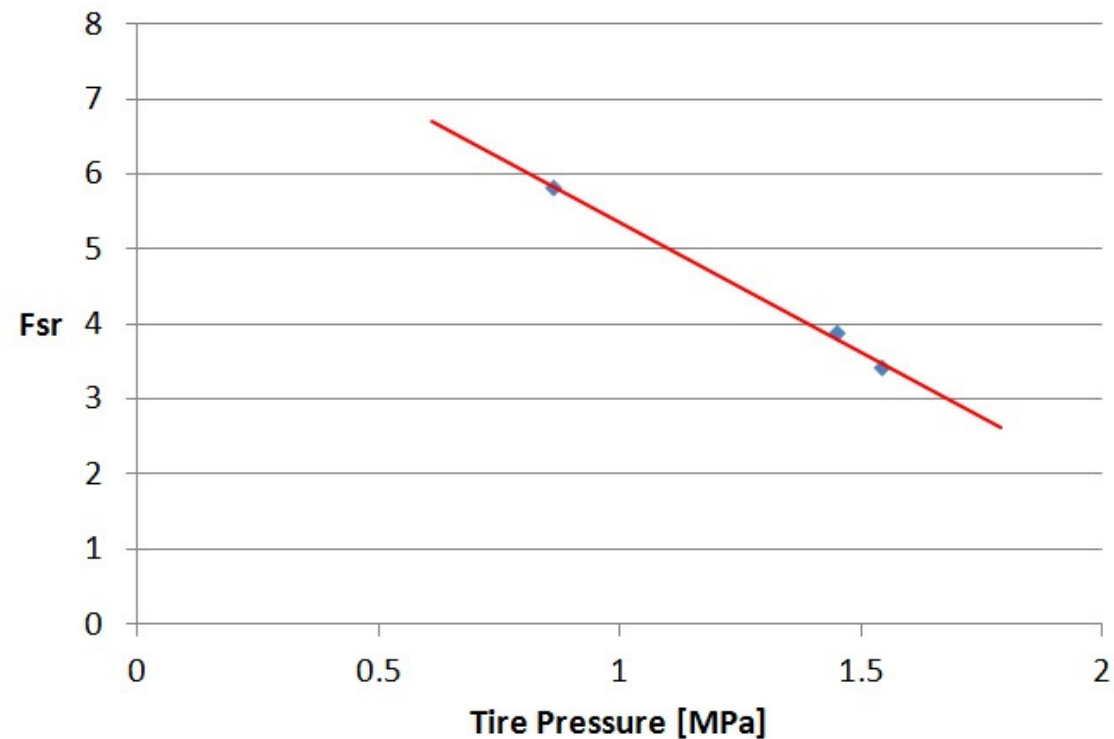## *Results – Loads in Curves*

- Tire Pressure = 1.54 MPa

- R = 35 m
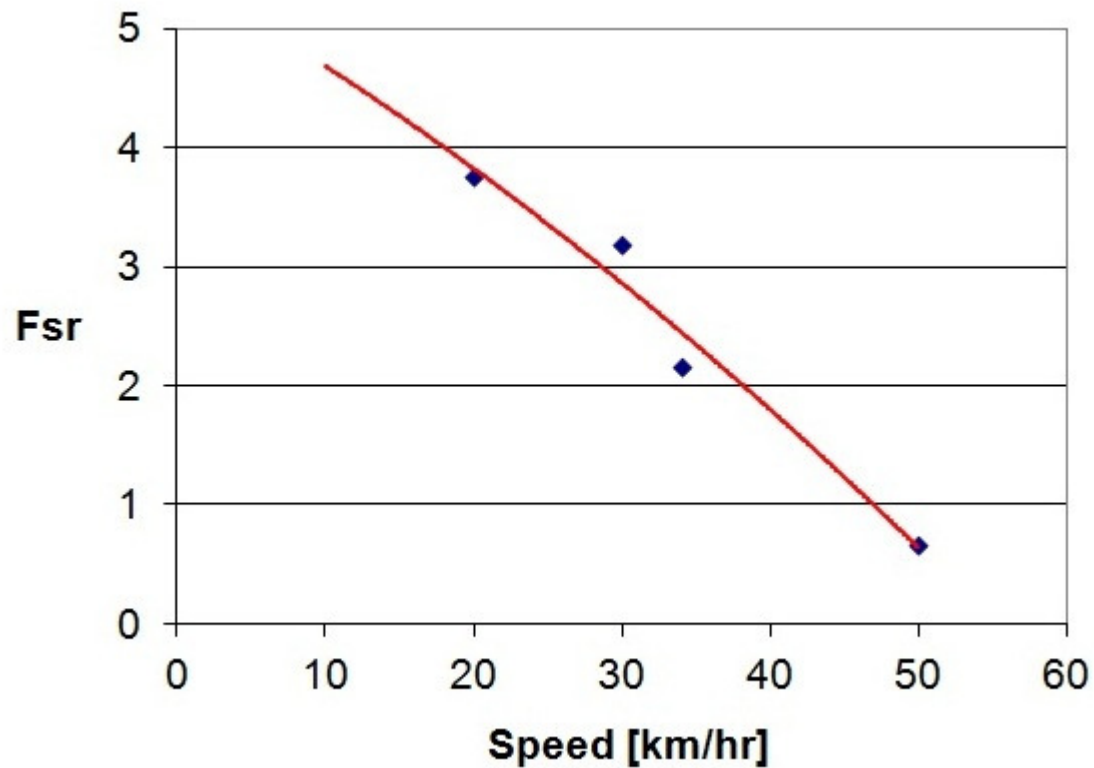
Numerical Calculations
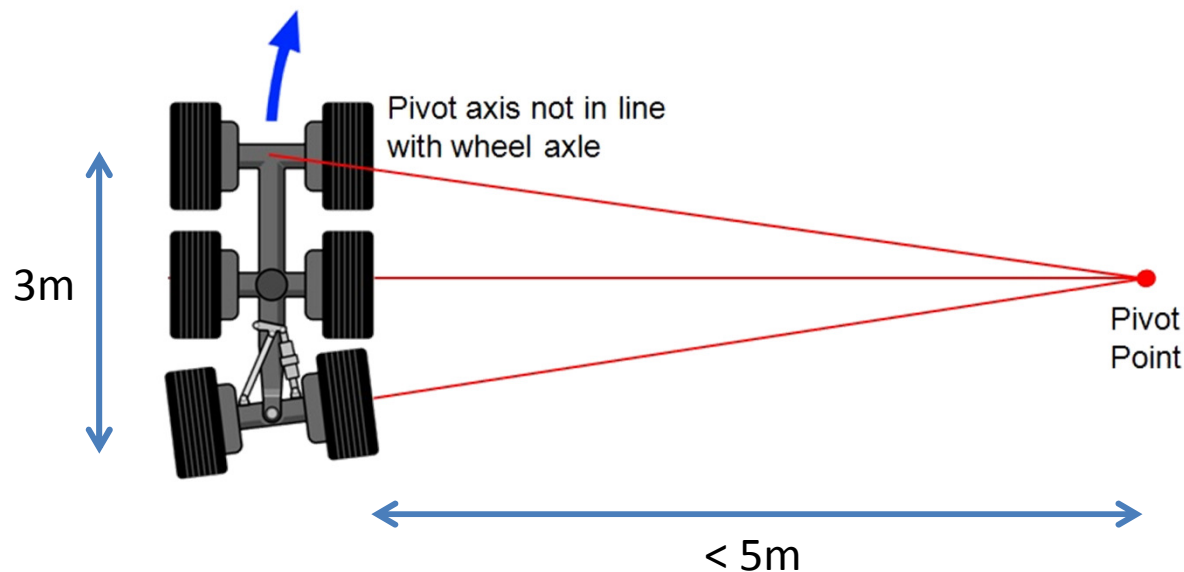
Results – Normal Pushback
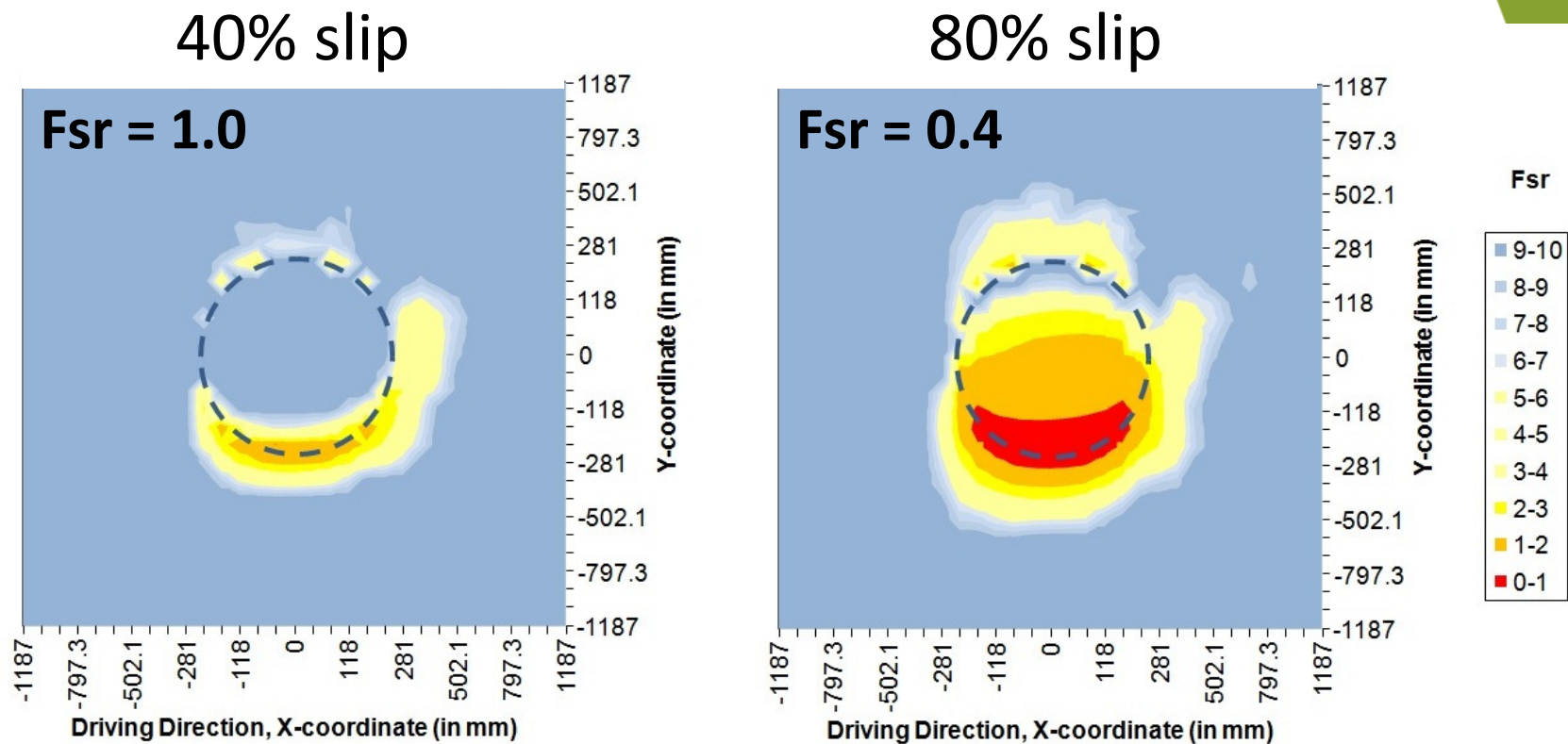
- v = 10 km/hr
- R = 10 m

Numerical Calculations

Results – Lateral Wheel Slip

- Normal push-back at low speed and r > 10 m → No risk

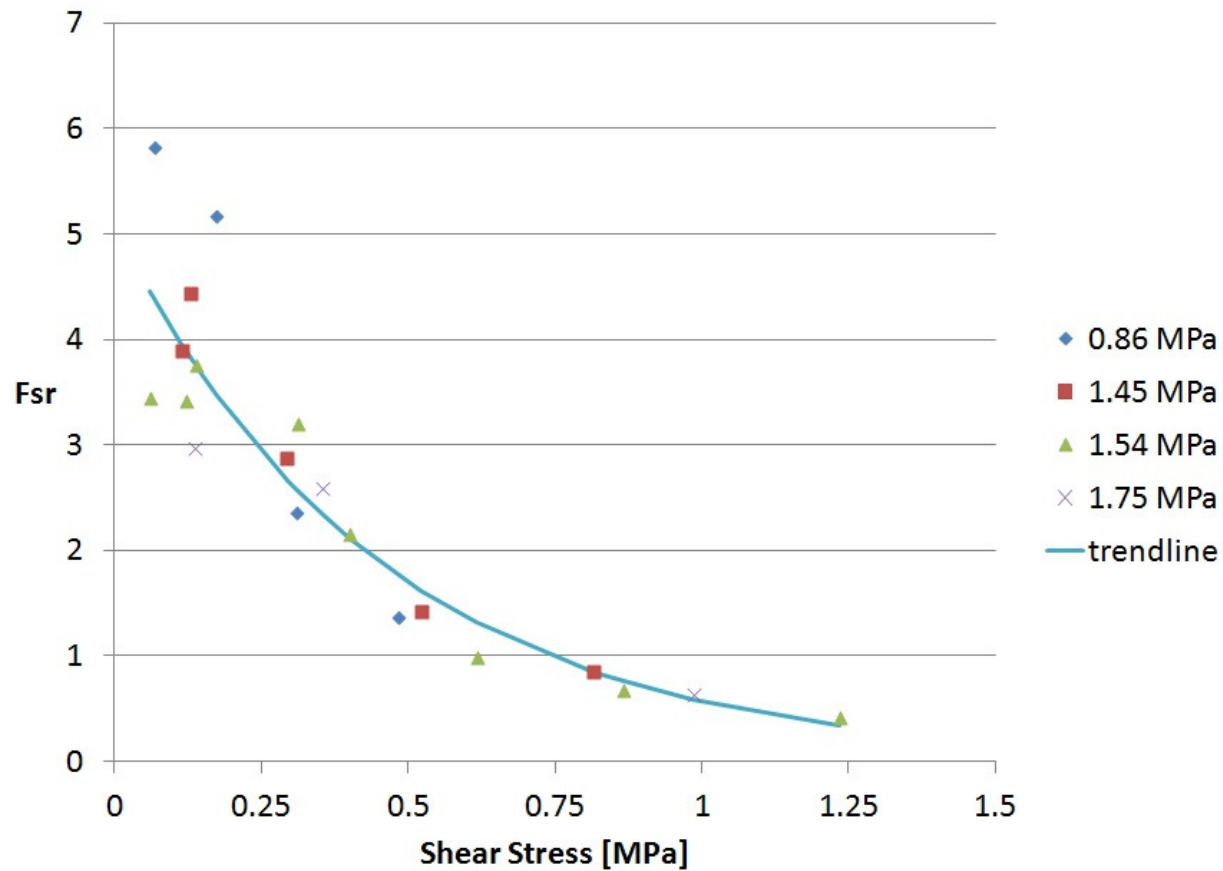- Extreme push-back, sharp steering angle → high risk with (tri)tandem axles due to wheel slip

Pivot axis not in line with wheel axle

Pivot Point

3m

< 5m

Numerical Calculations

Results – Lateral Wheel Slip
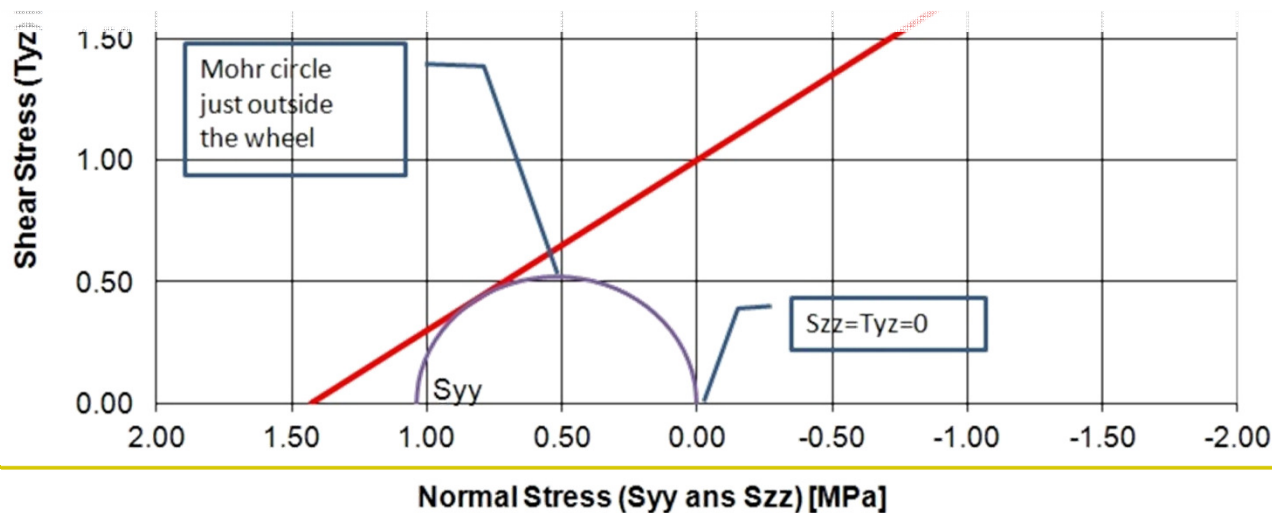
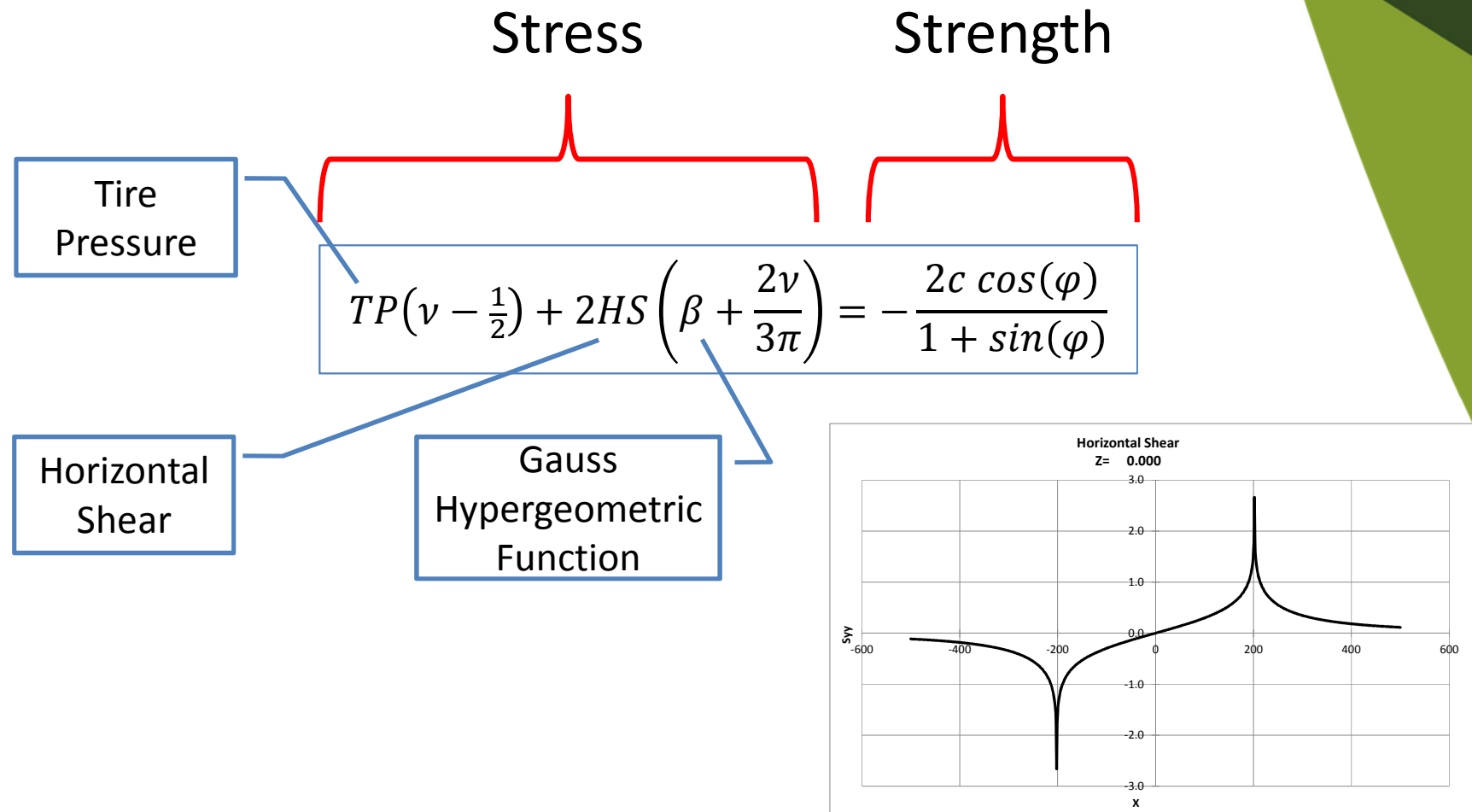40% slip

80% slip

Numerical Calculations

Summary

Analytical Model

- Gerrard and Harrison [1970]; Analytical model for stresses in uniform halfspace due to circular wheel load, also at z = 0 and y = r.

- Take stress condition just outside wheel; $\sigma_{zz} = \tau_{yz} = 0$

- Combine with Fsr failure model and take Fsr = 1

Analytical Model
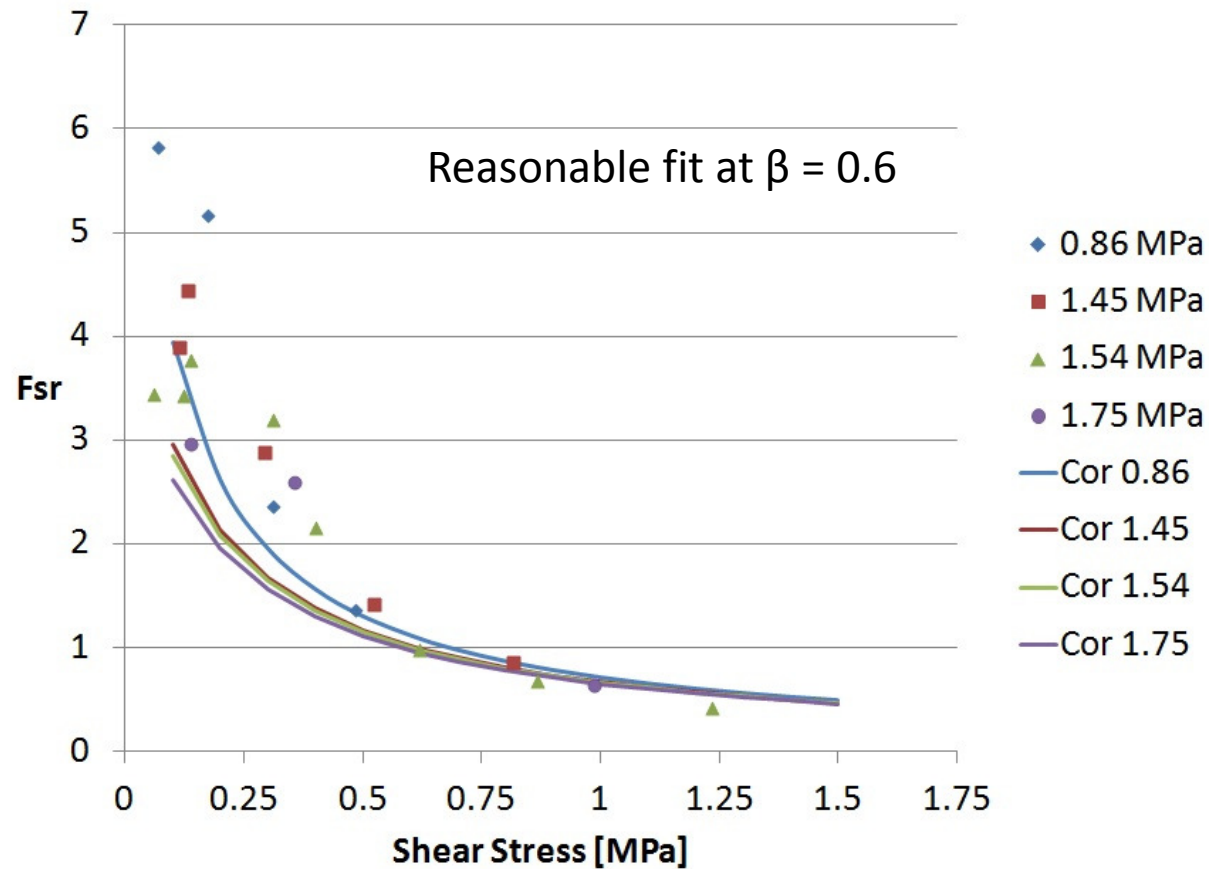
Stress   Strength

Tire Pressure

Horizontal Shear

Gauss Hypergeometric Function

$$TP\left(v - \tfrac{1}{2}\right) + 2HS\left(\beta + \frac{2v}{3\pi}\right) = -\frac{2c\,cos(\varphi)}{1 + sin(\varphi)}$$

Horizontal Shear
Z= 0.000

Analytical Model

Fit with Numerical Results

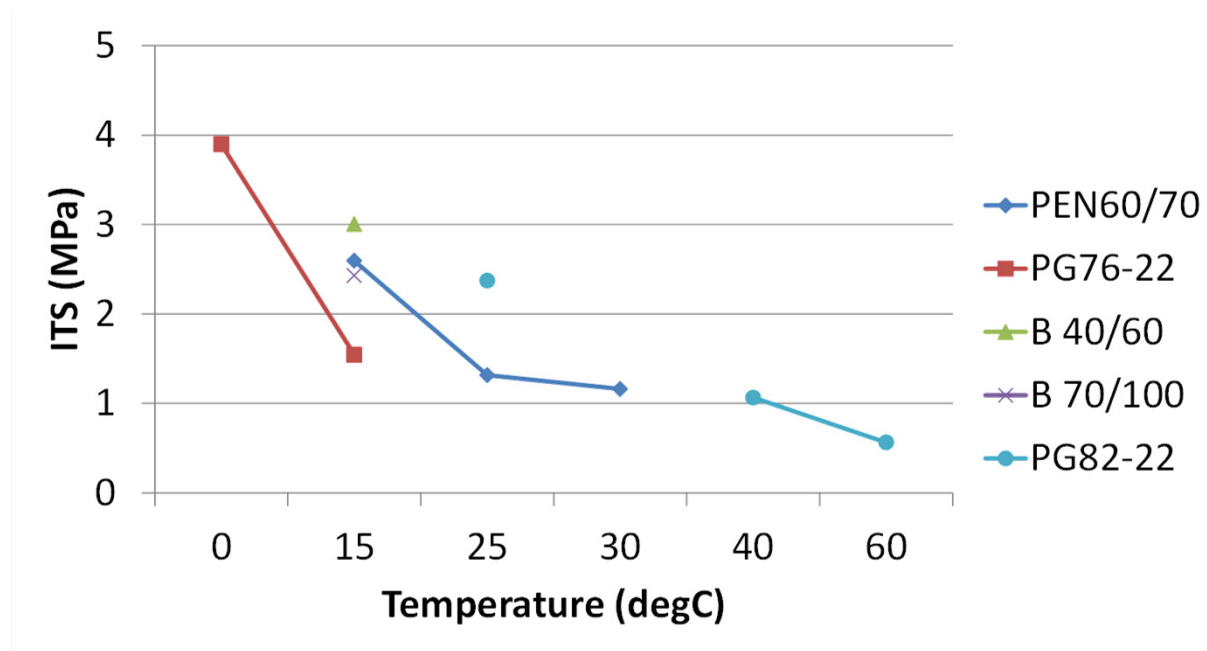Reasonable fit at β = 0.6

Mix Cohesion

Proportional to ITS and Sensitive to Temperature

Mix Cohesion = 1.75 x ITS (Christensen, Bonaquist)

Conclusions

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Thank you for your attention!

Download full report from:
http://www.crow.nl/publicaties/tire-induced-surface-cracking-due-to-extreme-wheel

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